

→ NORTH-AMERICAN CRYOSAT SCIENCE MEETING AND GEODETIC MISSIONS WORKSHOP

ESA's ice Mission Explorer. Seven years in flights
dedicated to monitoring Earth's ice fields and beyond

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On a Path Towards the Reassessment of Antarctic Volume Change: Synthesis of ESA Radar and NASA Airborne and Satellite Laser Altimetry Observations

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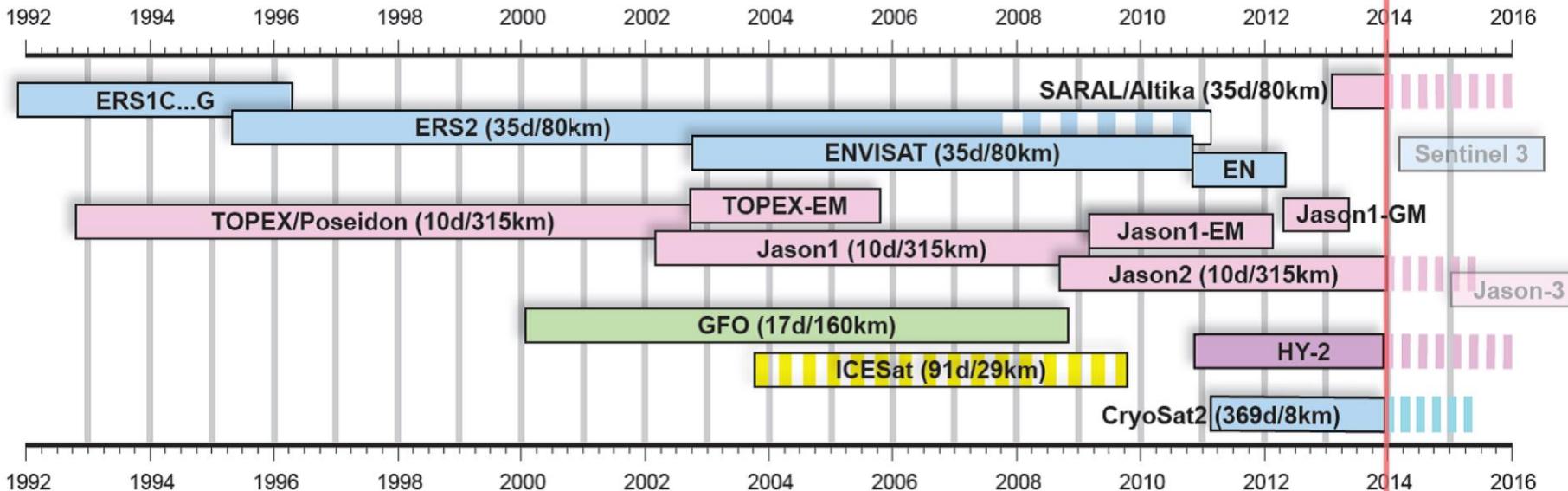
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Background

- Altimetry:
 - Longest continuous record of ice change
- Multiple type of sensors:
 - Laser and Radar
 - Differences in temporal and spatial coverage
- Quality of observations:
 - Varies with sensor system
 - Topography
 - Ground resolution

Long-term record



- Need to account for:
 - mission related biases
 - resolution and quality of observations
 - changes in surface scattering conditions

(Bosch et al., 2014)

Altimetry missions



- Satellite:

• ERS – 1	(1991-2000)	RADAR	PLF	(1.5 km)	ESA
• ERS – 2	(1995-2012)	RADAR	PLF	(1.5 km)	ESA
• Envisat*	(2002-2012)	RADAR	PLF	(1.5 km)	ESA
• ICESat*	(2003-2009)	LASER	BLF	(70 m)	NASA
• CryoSat-2*	(2010-2017)	RADAR	PLF/SAR	(1.5/0.35 km)	ESA

- Airborne:

• LATM**	(2009-2015)	LASER	BLF	NASA
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• LVIS*	(2009-2015)	LASER	BLF
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NASA

• LUTP*	(2008-2013)	LASER	BLF
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NASA

** Used for validation

* Included in analysis

Radar

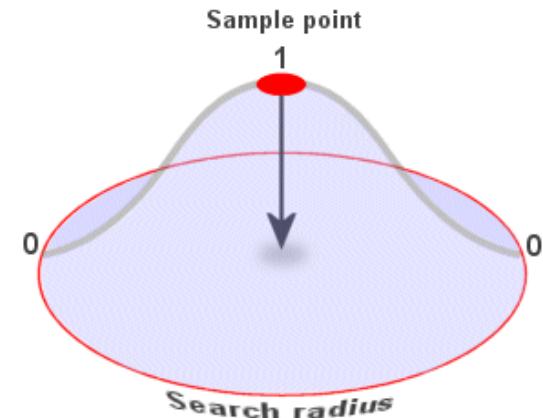
- Slope-induced error:
 - Relocation method
- CryoSat-2:
 - 20% threshold (LRM)
 - Adaptive threshold (SIN)
 - Baseline C
- Envisat:
 - OCOG (ICE-1)
- Backscatter correction:
 - RA2 and CS2
 - Sensitivity gradient

Laser

- Release 34:
 - G-C offset applied
- Constraints:
 - Waveforms with one peak
 - Saturation correction
 - Elevation usage flag
- Campaign bias:
 - Not applied
- Datum:
 - Topex/Posidon -> WGS 84

Merging procedure

- Removal of long-wavelength topography
 - Difference against DEM (Bedmap2)
- Adaptive search radius: 1 - 20 km
 - Improve spatial and temporal distribution
 - Ensure consistency in time series
- Least squares solution weighted by:
 - Standard error and distance from centroid
- Least-squares model: "A" (Design matrix)
 - Include residual topography (bilinear)
 - Temporal change (rate and acceleration)
 - Individual mission biases
 - Backscatter correlation
- Time series is re-constructed using the wanted parameters
 - Trend and acceleration



Adaptive least-squares minimization



- Adaptive least squares minimization:

$$x = (A^T W A)^{-1} A^T W y$$

- Weights: sensor precision (σ^2) and variable distance (d)

$$W = \frac{1}{\sum_{i=1}^{n_{\text{obs}}} \frac{1}{\sigma_i^2}}$$

- Robust solution of “Normal equations”

Least-squares model

- Least-squares parameter model:

$$dh = a(x_i - x_0) + b(y_i - y_0) + \frac{dh}{dt}(t_i - t_0) + \frac{dh^2}{dt^2}(t_i - t_0)^2 + c_{CS2} + c_{RA2} + \frac{dh}{ds}(s_i - s_m)_{RA2} + \frac{dh}{ds}(s_i - s_m)_{CS2}$$

- Design matrix: \mathbf{A}

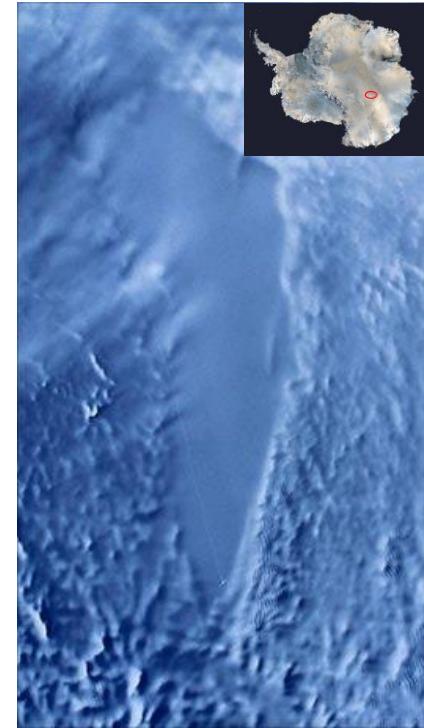
$$A = \begin{pmatrix} 1 & dx & dy & dt & dt^2 & dh_{ra2} & 0 & ds_{ra2} & 0 & \vdots \\ 1 & dx & dy & dt & dt^2 & dh_{ra2} & 0 & ds_{ra2} & 0 & \vdots \\ 1 & dx & dy & dt & dt^2 & dh_{ra2} & 0 & ds_{ra2} & 0 & \vdots \\ 1 & dx & dy & dt & dt^2 & 0 & dh_{cs2} & 0 & ds_{cs2} & \vdots \\ 1 & dx & dy & dt & dt^2 & 0 & dh_{cs2} & 0 & ds_{cs2} & \vdots \\ 1 & dx & dy & dt & dt^2 & dh_{ra2} & 0 & ds_{ra2} & 0 & \ddots \end{pmatrix}$$

- Re-construct time series:

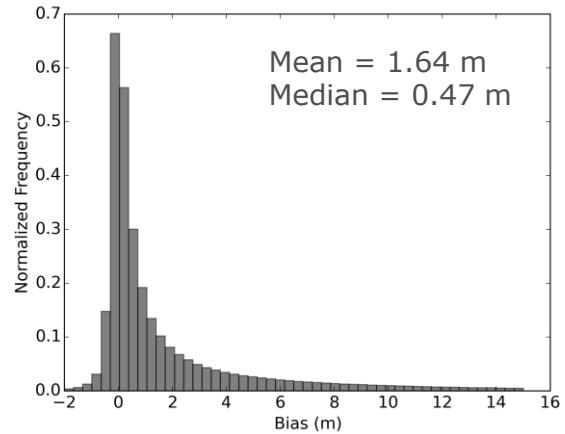
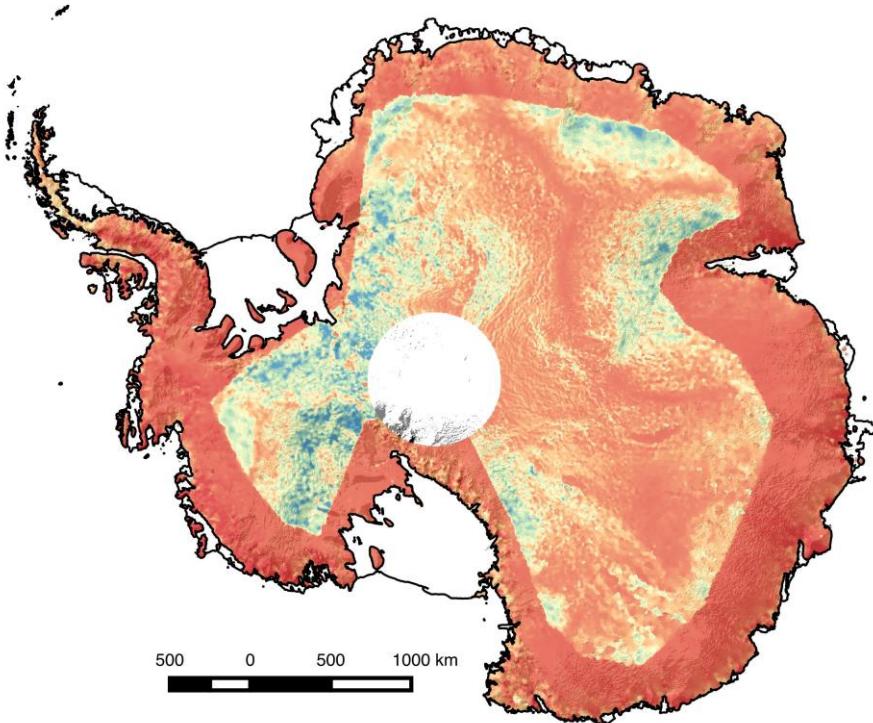
$$h(t) = r + \frac{dh}{dt}(t - t_0) + \frac{dh^2}{dt^2}(t - t_0)^2$$

Validation

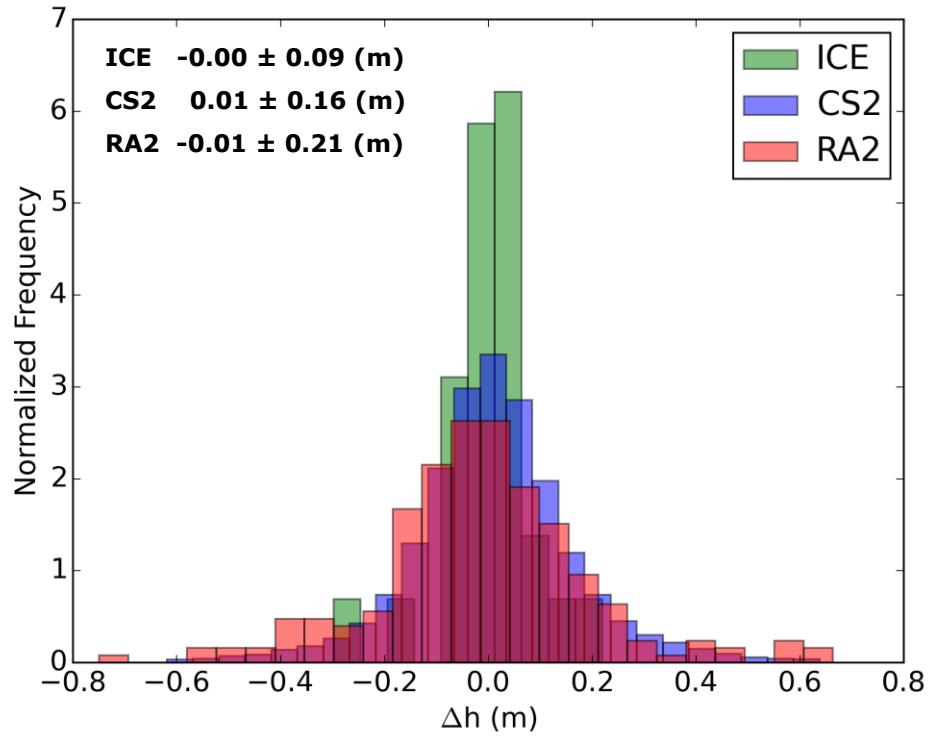
- Penetration bias:
 - Radar versus Laser
- Lake Vostok case study:
 - Crossover analysis
 - Correlation to backscatter
 - Sensitivity gradient
- Surface elevation change:
 - ATM versus merged solution



Radar penetration bias

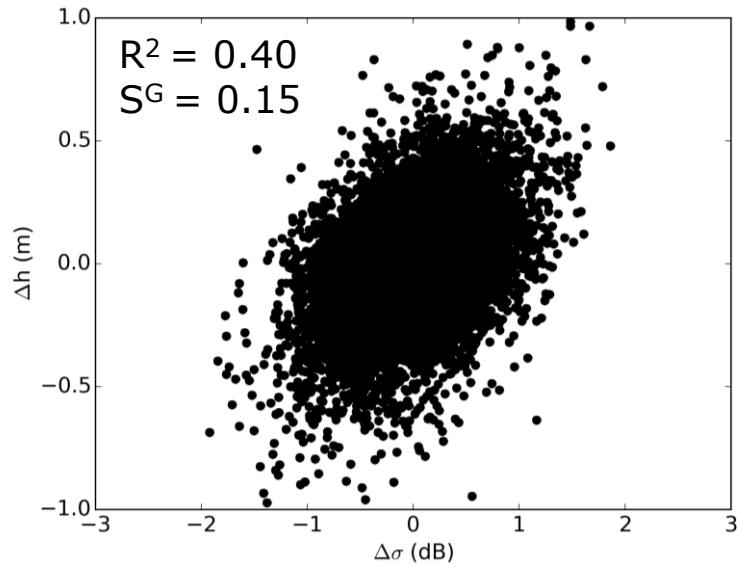


Crossover analysis

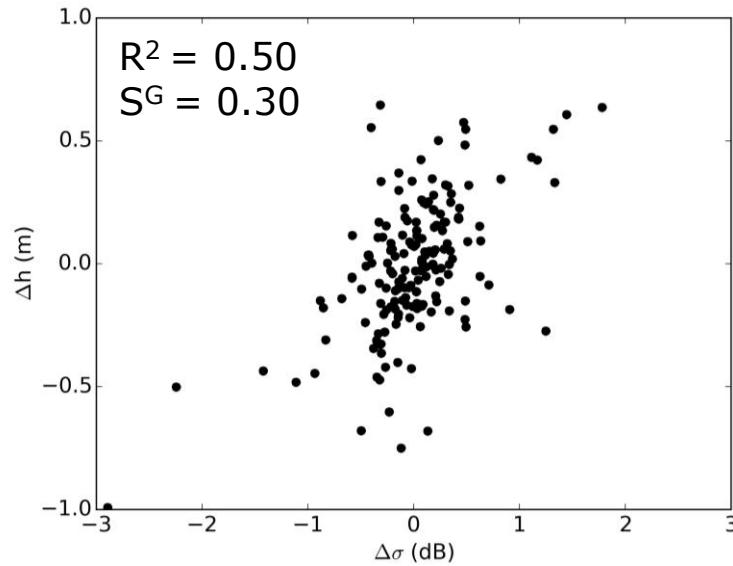


Backscatter correlation

CryoSat

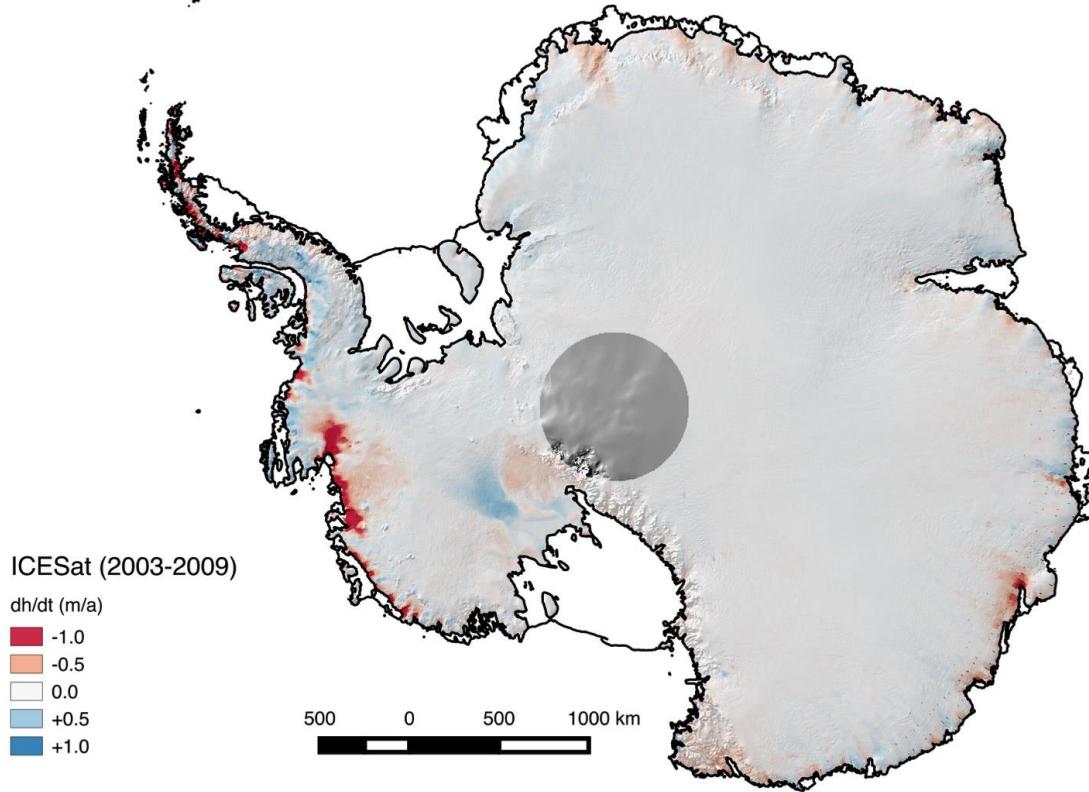


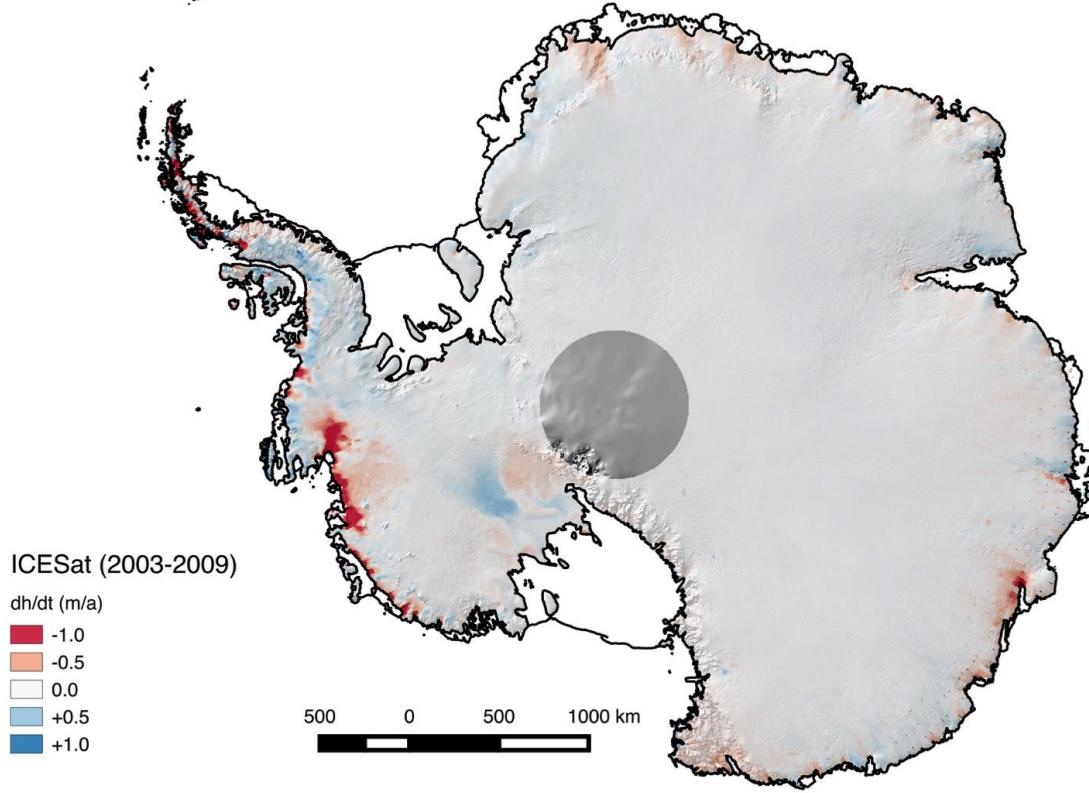
Envisat



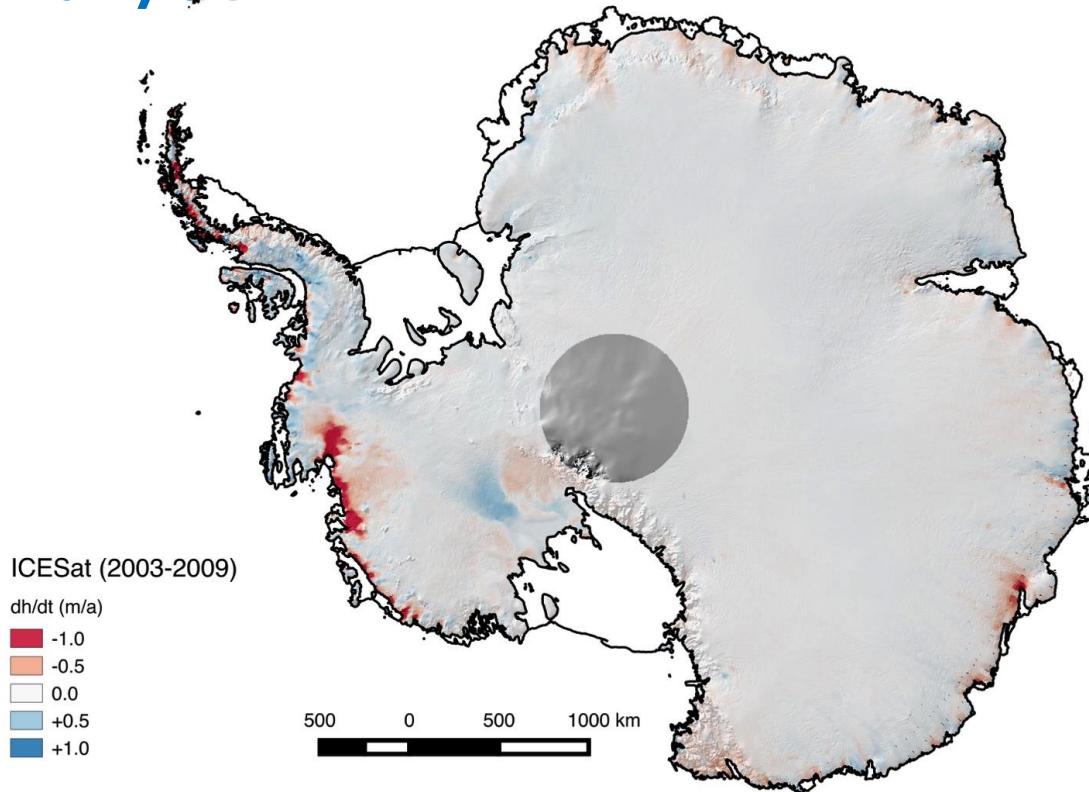
Results

- Surface elevation change individual missions:
 - CryoSat -2 (2011 - 2016)
 - ICESat (2003 - 2009)
 - Envisat (2003 - 2012)
- Surface elevation change merged product
 - Merged (2003-2016)
 - Spatial pattern
 - Time series from example areas

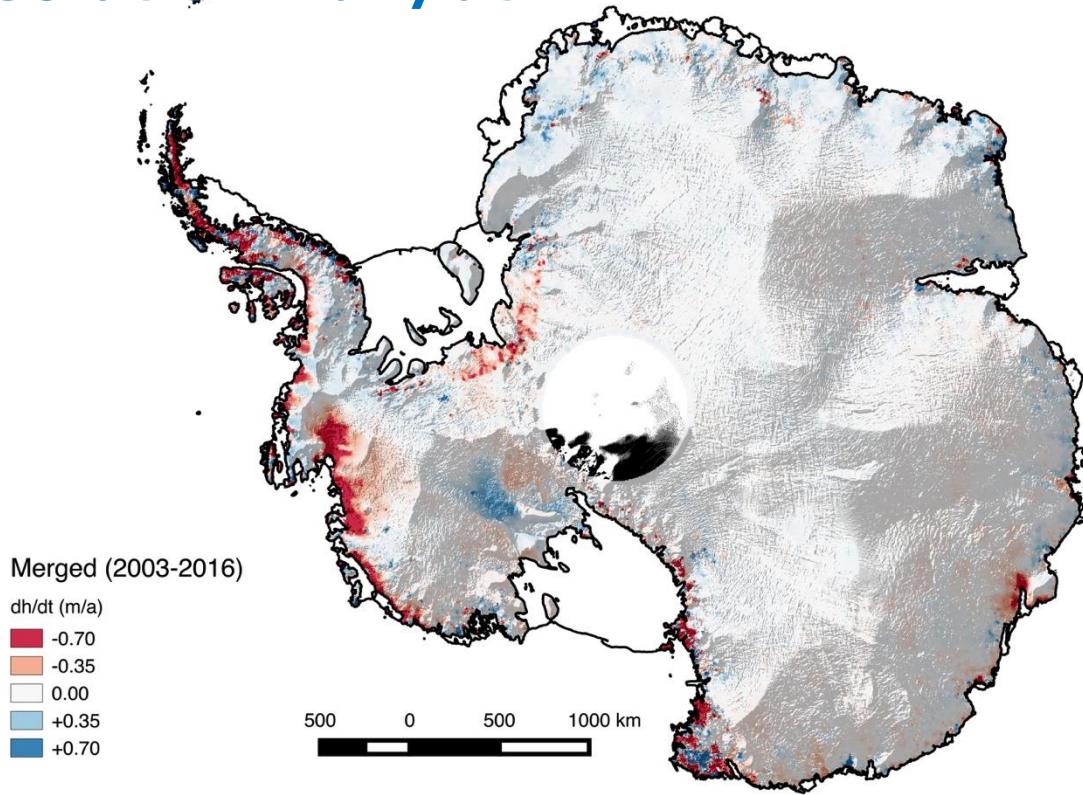




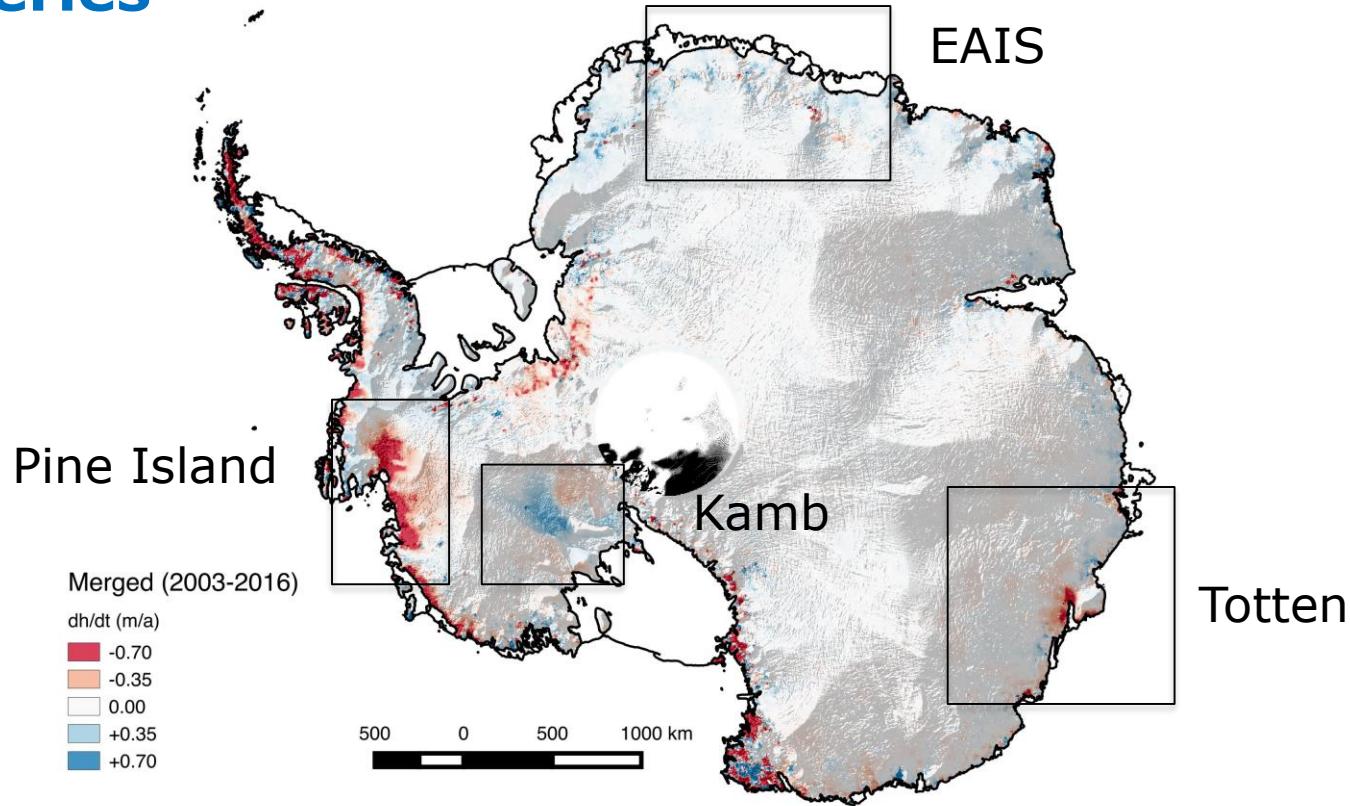
Envisat – dh/dt



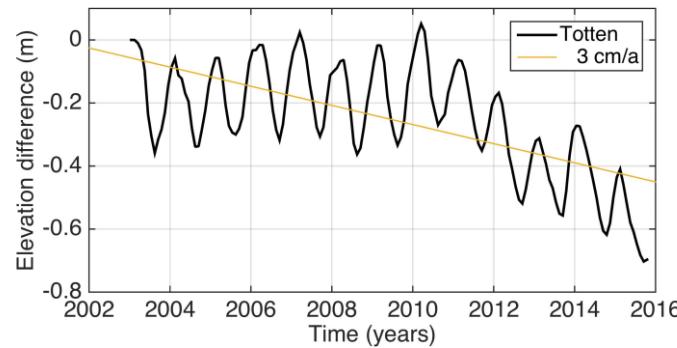
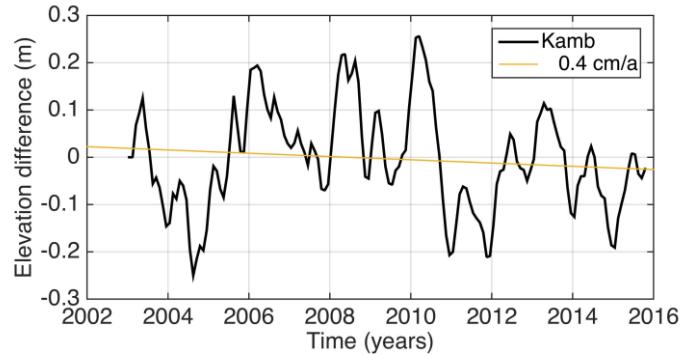
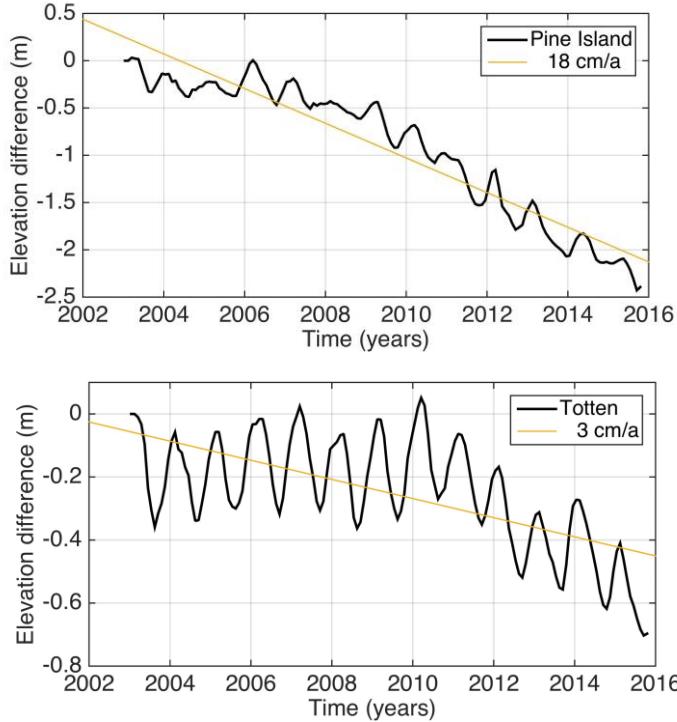
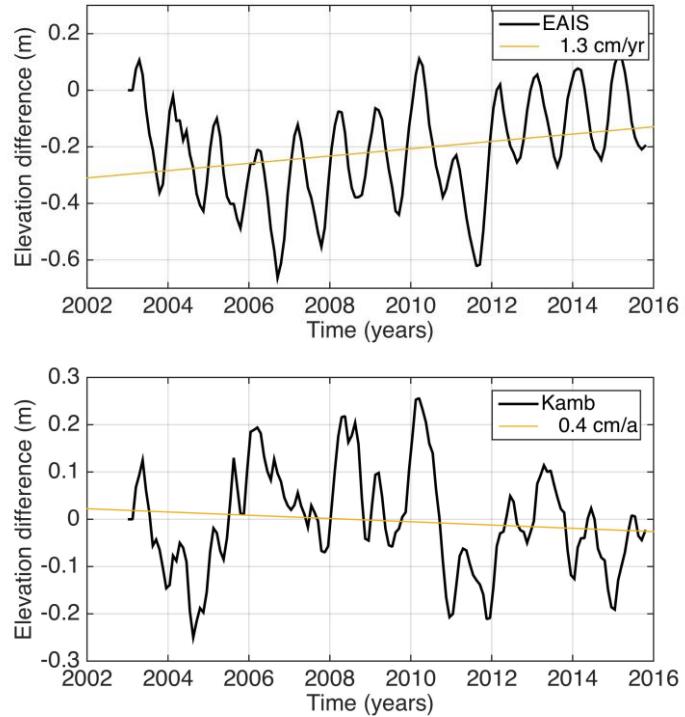
Merged solution - dh/dt



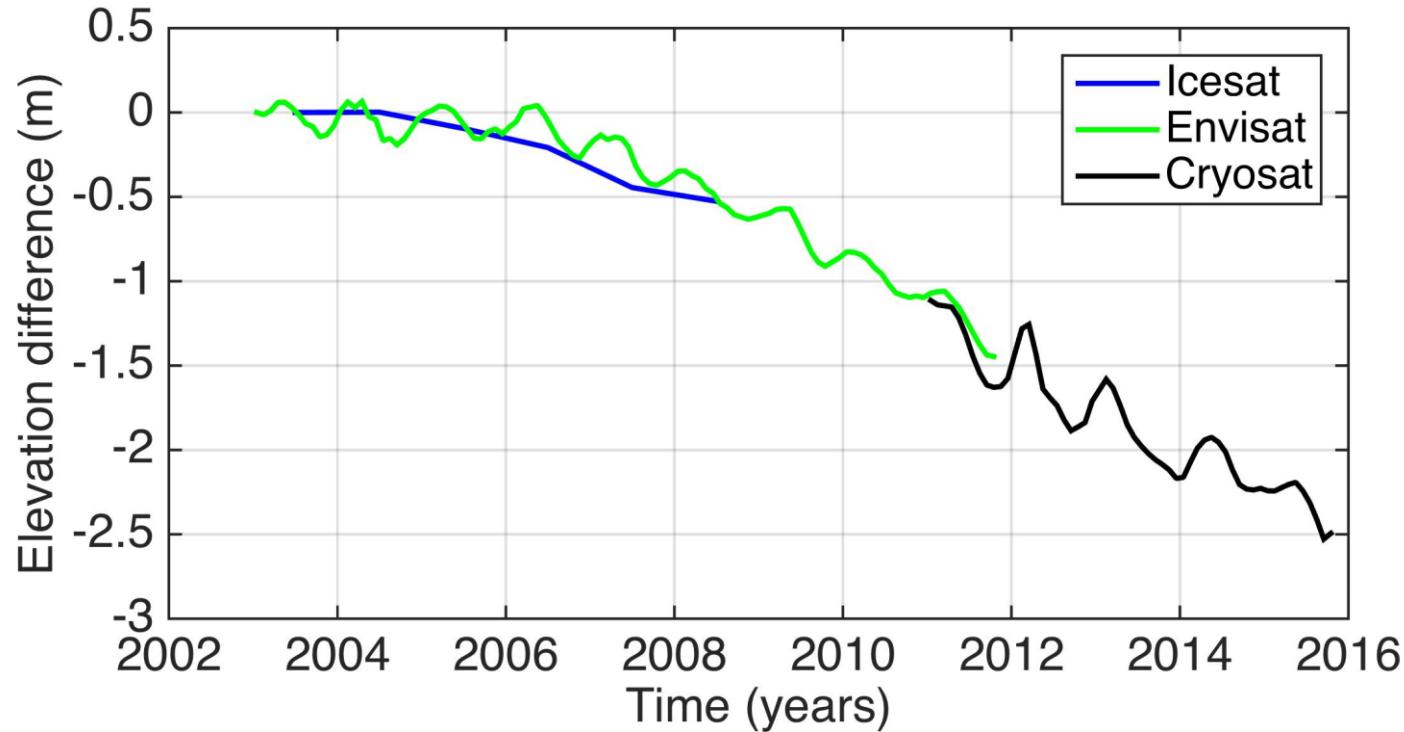
Time series



Time series



Time series – Pine Island and Twaiths



Future work

